Geodesic Head Web Design

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The Geodesic Head Web (**Figure 1**) represents a significant advance in high-density EEG electrode application. It builds on the advantages of earlier designs, including rapid application of a high density array with saline-sponge electrodes, and extended monitoring available with gel electrolyte. Importantly, it is designed for use with high input impedance amplifiers, allowing good quality EEG recordings with higher electrode-scalp impedances (up to 100K Ohms) and therefore avoiding scalp abrasion and the associated infection risk (Ferree, Luu, Russell, & Tucker, 2001).

Figure 1. The 130 channel Geodesic Head Web.

Several minor improvements are significant for daily use. An improved sealing of the wire-electrode junctions, explicitly tested by quality control inspections, minimizes electrode failures. Furthermore, a new lightweight, robust connector with a custom housing facilitates rapid alignment and insertion into the amplifier or articulated arm.

Most importantly, a new geodesic tension structure has been designed and patented to improve how a robust tension structure (the web) can fit diverse head shapes. This is an important advance in the evolution of geodesic designs (**Figure 2**).

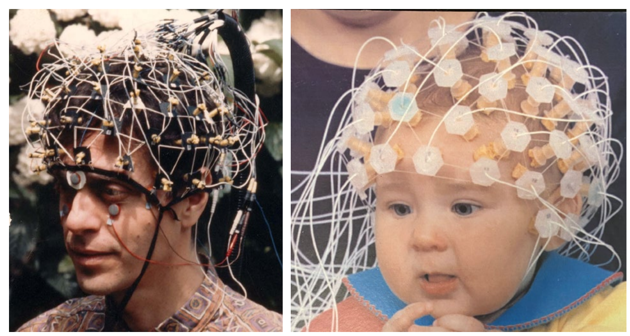

Figure 2. Early geodesic designs.

Our earlier design efforts used a simple icosohedron geometry (**Figure 3**) (D. M. Tucker, 1993) that did not easily fit the ellipsoidal or spheroidal head shapes of different people. To fit different heads with the triangular shape, a thin and highly stretchable elastomer was necessary, and this led to general fragility with easily broken elastomer lines.

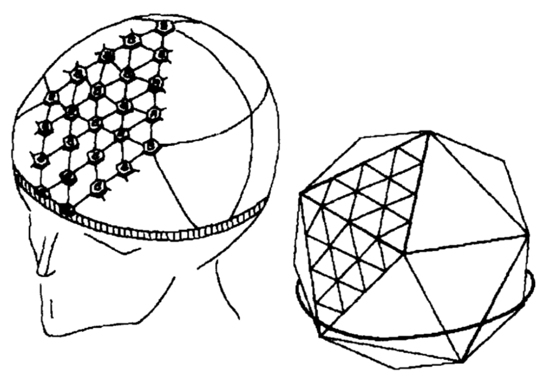

Figure 3. Icosahedron design of the previous generation (Geodesic Sensor Net, purchased by Philips in 2017, now sold by Magstim EGI).

Too Floppy, Uneven Tension, and Too Many Electrodes on the Face

In addition, this high stretchability caused application to be somewhat unreliable unless the user had a high degree of skill in adjustment and placement. The cut-outs around the ears made it difficult to adapt to individual differences in ear positions, and the resulting lack of even tension across the sides of the head led to poor tension at the back of the head, and thus poor electrode contact, particularly for participants with long hair. Finally, the previous design had too many uncomfortable electrodes placed on the face. Although some coverage of the face is important (given the unique brain fields projecting there), too many electrodes on the face was unnecessary and awkward.

The new design of the Geodesic Head Web addresses each of these issues. We can now use a more robust elastomer because of a new geodesic tessellation (truncated icosahedron or soccer ball design) that minimizes stretch required to extend the 2D elastomer to 3D head shapes. An important benefit is better fit for various head shapes of diverse participants.

A Modular Pentagonal Element for Constructing a Truncated Icosahedron

A *geodesic* is the shortest distance between two points on the surface of a sphere. Because materials constructing the spherical surface of a head net or web are typically formed initially in 2D, the generalization of 2D elements to the 3D spherical or ellipsoidal head shape can be approached through the classical polygonal objects. As shown in **Figure 3**, the original icosahedron design (D. M. Tucker, 1993), was a somewhat crude approximation to the spheroidal head shape.

A well known polygonal sphere is the soccer ball, constructed with a *truncated icosohedron*. Imagine that each point of the icosohedron in Figure 3 is cut in a plane defined by a cord of the sphere. The result is a pentagon in that plane, constructed from the 5 triangles that met at the point (black pentagons in **Figure 4**). The pentagons are then interposed among hexagons newly formed by the truncation cuts.

Figure 4. Truncated icosahedron or soccer ball design.

The goal of the design is translating 2D elastomer sheets to the 3D sphere surface with a minimum stretch to maintain robustness and minimize line breaks. This was accomplished with the modular pentagonal element (MPE) patent (Don M Tucker, Luu, & Shusterman, 2021). The MPE is a division of the truncated icosohedron design into the smallest number of component elements, achieved by extending each pentagon to incorporate electrode positions within the adjacent hexagons (**Figure 5**). The MPE components are then assembled to the spheroidal head shape through electrode positions that are shared by adjacent MPEs (**Figure 5**).

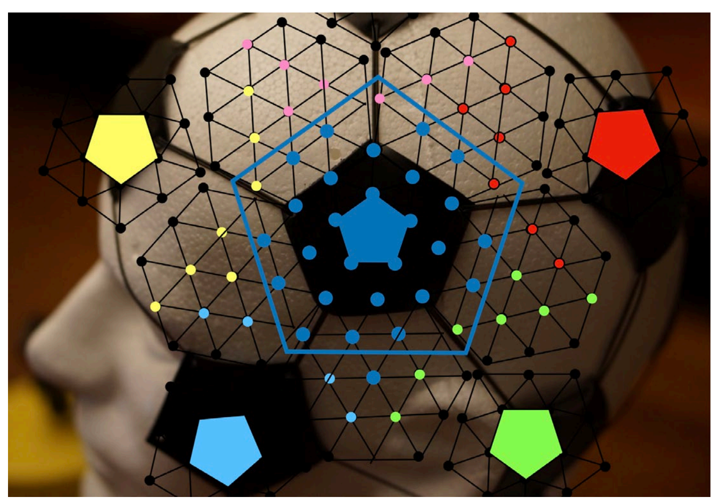

Figure 5. Illustration of the MPE (blue) that contributes hexagonal fragments to the adjacent hexagons, along with the contributions of additional MPEs and their contributions.

The design of the Geodesic Head Web **(Figure 6)** builds on this robust elastomer geometry to solve a number of problems caused by the earlier elastomer fragility. The geodesic tension structure extends over the ears, rather than having cut-outs for the ears, so that even tension is achieved across the head, including the back of the head where contacts were typically poor. In addition to even tension, this design improves ear comfort by keeping electrodes around the ear in their proper place on application, eliminating the ear adjustment techniques needed with the previous icosahedron design.

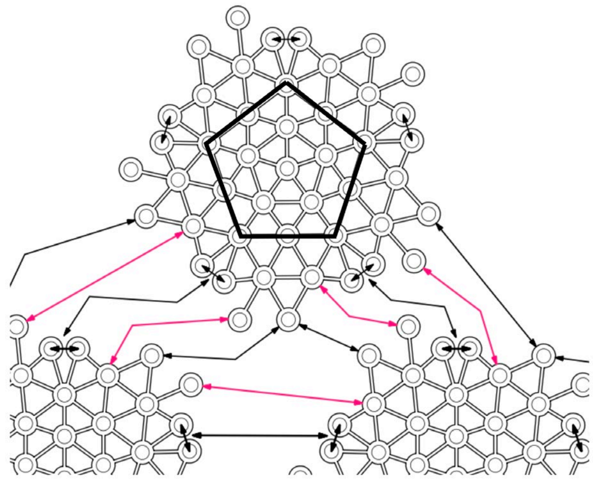

Figure 6. The MPEs allow the head web to be assembled with an optimal 3D spheroidal approximation with the minimum number of component elements.

Because the elastomer is not so thin and floppy, we were able to minimize the tension adjustments, so that only one adjustment cord lock is needed under the chin (Figure 1). In addition, we minimized the face electrodes to improve comfort, and still provide basic electrical field sampling for this head surface area.

The overall goal of these design improvements was to create a more robust electrode system that is easier to apply accurately. This means that application and adjustment is also faster, and more repeatable across applications. Our application tests, including training of novices to apply the Geodesic Head Web, in both 130 and 280 channel counts, confirms that the skill required for accurate application is much less challenging. The entire head web is a more integrated structure that can be quickly positioned in relation to skull landmarks, then secured with a single chin strap adjustment.

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Truncated icosahedral neural sensor net and modular elements therefor. US. Pat. No. 11,045,131.